# Classifications of Unconventional Resources in Kuwait*

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## Abstract

Over sixty years of intensive E&P activity has resulted in the identification of most of the large structural plays and conventional reservoirs. These efforts have seen the establishment of hydrocarbons in reservoirs ranging in geologic age from the Palaeozoic to the Tertiary. To meet the ever-increasing demand for hydrocarbon resources and to maintain its competitive position in line with Year 2040 target, KOC has embarked upon an aggressive campaign to establish and develop unconventional reservoirs in this largely mature oil province. An initial assessment suggests that Kuwait has a huge potential in its unconventional resources. As the conventional resources are already in mature stage of exploitation, KOC is working on various strategies for the development of its unconventional resources.

The present study and approach as outlined in this paper is to consolidate the potential of various unconventional resources of Kuwait and to classify them for an effective exploitation and development scheme. These resources have been classified into three major types viz., Organic-rich formation (Class-I) which are the main source rocks for the oil and gas across the entire Kuwait, Tight formations (Class-II) and Mobile/immobile heavy oil reservoirs (Class-III). However, the current focus is on the exploitation of kerogen rich zones of Class-I.

Based on detailed evaluation, it has been established that Kuwait has a huge potential of unconventional resources in Jurassic Najmah-Sargelu and Makhul formations of cretaceous age. However, exploration and development of these resources is very challenging because of the complex structural setup. In addition, the major challenge in the exploitation is due to its disposition in terms of thickness and depth of occurrence. These resources though are of huge lateral extent, they are encountered at relatively greater depths and in relatively thinner rock units.

However, the challenges of exploitation of unconventional resources of Kuwait can be attributed to the completion and fracture design strategy, which will be governed by the distribution of regional and local stress patterns and other geomechanical parameters. Another important aspect is that exploitation of unconventional resources involves huge capital expenditure and hence involves proper planning and proactive strategies.

## Introduction

Definitions and classification frameworks are numerous and highly variable and there are no industry standard definitions for the unconventional resources. Current definitions of unconventional resources are diverse dependent upon geologic and petroleum system interpretation, fluid property consideration, technological barriers and economic flow rate requirements. The unconventional reservoirs term is commonly used to describe a reservoir, which contains a significant amount of hydrocarbons, but is difficult to produce for a variety of reasons. These may include structural complexity (i.e. low permeability, especially in excessively fractured reservoirs), limited reservoir access based on a remote location, and/or production and handling contingencies requiring technologies that are not yet developed. It is worth mentioning that categorizing certain types of reservoirs as either conventional or unconventional has been an issue for the industry, one in which no clear line can differentiate between the two.

The other reservoirs, which could be considered under Unconventional varieties, are Tight reservoirs and heavy oil reservoirs. This paper outlines the classification of unconventional resources of Kuwait, also the challenges associated with the exploration and development of unconventional resources along with the strategies to develop these resources in the near future. The formations categorized unconventional resources belong to the Lower Cretaceous through Upper Jurassic Formations. These formations contain organic-rich zones with very high TOC and are known source rocks for the major reservoirs all across the Kuwait. The Makhul Formation, stratigraphically above Gotnia Formation evaporites and Najmah Sargelu just below the Gotnia evaporites, are significant contributors for Kuwait's Jurassic and Cretaceous hydrocarbon accumulations.

## Stratigraphy and Depositional Setup

The Arabian basin spans (Figure 1) much of the present-day Arabian Peninsula and Arabian Gulf. It is bounded on the southwest by the Arabian shield and on the northeast by the Zagros fold belt. Until its collision with Eurasia during the Tertiary Period, the northeastern margin of the Arabian plate formed the southern boundary of the Tethys Ocean. The basin structure evolved from a sag basin in the Paleozoic to a Mesozoic-age passive margin. Tertiary-age compressional structures near the Zagros fold belt formed due to collision of the Arabian plate with the Eurasian plate as the Arabian Basin transformed tectonically into a foreland basin. The primary unconventional resources of Kuwait comprise Najmah Kerogen of Jurassic and Makhul Shales of Cretaceous age.

## Structural Elements and Regional Stress Field

The onshore structural elements of Kuwait demonstrate significant variation in trend. This variation depicts the interaction of a principal horizontal stress which has ranged through a Northeasterly arc (NNW to E) from Early Cretaceous to recent times, and a structural grain inherited from the basement. The present day maximum horizontal stress field is northeast-southwest. The present-day northeasterly trend for the Principal Horizontal Stress field is consistent with other trends on the Arabian Plate (Akbar and Sapru, 1994) reported as the Zagros Stress field in the Oman and Abu Dhabi region (Marzouk and El-Sattar, 1995). Regional stress field indicators based on wellbore breakout data from Caliper logs and open fracture trends from image logs is represented in Figure 2.

## Unconventional Resource Classification and Development Stages

An unconventional reservoir is generally defined as a reservoir with less than 0.1 millidarcy permeability and that requires hydraulic fracture stimulation to flow at economic rates. However, to define potential unconventional resources of Kuwait, additional minimum requirements were applied in the choice of various reservoir parameters and cut-offs viz., an effective porosity greater than 2%, effective hydrocarbon saturation greater than 55 percent, reservoir thickness greater than 25 feet, and for shale resources, 50 ft of greater than 1 % Total Organic carbon. Of the various intervals initially identified, Kerogen rich intervals of Jurassic Najmah and Lower Cretaceous Makhul Formations displayed a huge potential for unconventional hydrocarbons.

After a series of deliberations and discussions, based on KOC's business needs, the unconventional resources in Kuwait are classified into three main classes for effective implementation of strategy, reservoir characterization, and development. Unconventional resources in Kuwait are divided broadly into 3 categories as presented in Figure 3. The typical log signatures of these classes of resources are represented in Figure 4.

**Class-I Unconventional Kerogen**: Defines organic rich/Kerogen prospects that are further subdivide into two subcategories:

- Class IA: Self sourced kerogen/organic rich intervals
  - Makhul, Najmah and Base Gotnia kerogen are the prospects currently definitely identified in this category.
  - There are other formations that could be potentially included in this category but further study is required to identify these.
- Class IB: Kerogen and Limestone intercalations
  - Lower Najmah Kerogen (Najmah MFS) kerogen and limestone intercalations, developed currently as a fractured limestone and is considered as a separate sub category.

**Class-II Unconventional Tight**: incorporates tight clastic or carbonate formations with low organic material content, for example the Marrat tight limestone. Permeability is less than 0.1 millidarcy (mD)

**Class-III Unconventional Viscous Oil**: involves both immobile and mobile oil

- Class IIIA: Mobile: relates to mobile viscous oil of less than or equal to 10,000 centipoise viscosity, current development of Lower Fars under production appraisal.
- Class IIIB: Immobile: relates to immobile viscous oil exceeding 10,000 centipoise viscosity and it includes tar-mat and bitumen, e.g. Tayarat.

The current focus of tapping unconventional resources is primarily on the Class IA - Kerogen rich intervals of Makhul, Najmah and Base Gotnia Formations of lower cretaceous and Jurassic Age. Therefore, this paper is focused mainly on Class-IA; other classes are still in study stage and need more data acquisitions and analyses for further detailing and assessment.

Table 1 shows the envisaged process flowchart for the Exploration and development of unconventional resources for Class-IA in Kuwait. Four stages in the exploration and development process for unconventional Class IA were identified. Each stage of the exploration and development process for unconventional Class IA reservoirs is meant to include robust analysis before decisions are made to proceed with the following state or abandon the project.

**Stage-1** involves the compilation and inventory of existing data as well as supplementing that dataset to allow for a complete interpretation of seismic and well data. A structural, natural fracture, geochemical, and geomechanical review should be completed prior to the construction of an initial model. Properties such as hydrocarbon density, thickness, and maturity should be integrated and mapped. The final steps of Stage-involve identifying preliminary “sweet spots”, volumetric estimation and the quantification of the associated development risks. Should the project demonstrate potential at the conclusion of Stage-1 analysis, the decisions to be made include whether to proceed with an exploration pilot program, and, if so, what are the best locations for that potential pilot.

**Stage-2** focuses on the pilot program. Wells should be planned, designed and simulated before vertical and horizontal wells are drilled into the proposed pilot areas. Data acquisition at this stage should seek to further define reservoir characteristics and refine completion/fracture design. All vertical and horizontal wells should be fracture stimulated and monitored, using microseismics and production tests. Following this data acquisition and testing period, the geological, geomechanical, and structural models should be improved leading to further refinement of the volumetric estimation. Key decisions, which follow the completion of Stage 2, include whether to proceed with an appraisal project, and, if so, what is the best location for that potential appraisal.

**Stage-3** focuses on the appraisal program. Additional wells should be drilled in the selected appraisal pilot locations with the key objectives being the iterative optimization and refinement of drilling operations, refinement of sweet spot location identification, completion design refinement based on additional production tests, and additional data acquisition to assist in fine-scale modeling to maximize the Stimulated Rock Volume (SRV). All available data should be used to refine the geological, geomechanical, structural and reservoir models, ultimately leading to an estimation of SRV and reserves. Upon the classification of reserves, the development risk can then be defined which includes the implementation of detailed cost analysis to show potential commerciality. Should Stage 3 prove successful, the key decision to be made is whether to proceed with development

**Stage-4** focuses on the development of the unconventional resource. Much like Stage 3, drilling, sweet spot location and completion design should be iteratively optimized and refined. Well patterns should be optimized in corroboration with production rates to maximize EUR. Drilling and completion processes should be industrialized as much as possible, and the key focus should be the aggressive control over and reduction of all costs.

## Unconventional Resource Potential – Jurassic Source Rock- Unconventional Play

Recently, a very comprehensive study was carried out to identify and volumetrically assess the resources in self-sourced organic rich intervals and tight formations. The study was carried out for unconventional hydrocarbon characterization and evaluation by the integration of cores, well logs and seismic data. The outcome of the study indicated significant unconventional resource potential primarily from the following two intervals of Jurassic and Cretaceous formations:

- Jurassic Callovian to Oxfordian Najmah Formation characterized by a lower, black to dark gray, marine shale unit overlain by a well-cemented packstone, argillaceous, and bituminous limestone. Petrophysical modelling results consistently identified the upper portion of the Lower Najmah Shale as the principal kerogen-rich zone exhibiting world-class source rock potential. The Kerogen-rich zone consists of calcareous, black shale typically 40 to 50 feet in thickness and bound by the Najmah Limestone on the top and the Sargelu Formation Limestone at the base.
- The Cretaceous Berriasian Makhul Formation dominated by marine carbonates (Upper Makhul Formation) and its laterally equivalent deep marine shales (Makhul Formation). Petrophysical model results consistently identified the lower Makhul Formation as Kerogen-rich zone and a potentially good source rock. The upper Makhul Formation consists of interbedded tight limestones and shales.

The following is the brief description of lithostratigraphic units of Jurassic-Cretaceous intervals of Kuwait, which are considered to be potential Unconventional resources of Kuwait (Figure 5).

**Sargelu Formation**

Sargelu Formation is considered as the second potential reservoir within the Jurassic section. This Formation is mainly composed of interbedded wackestone packstone and mudstone with some Bitumen. This formation is conformably overlying Dhruma and underlying the Najmah Formation. The distribution of the lithological components within this Formation indicates that the energy level has been increased gradually upward.

**Najmah Formation**

Najmah Formation represents the upper-most carbonates of the whole Jurassic section. It is mainly composed of interbeds of cemented peloidal packstone, argillaceous limestone and bitumen. In Kuwait, the Najmah is uniform and correlatable across the study area, emphasizing the widespread nature of the flooding event that took place during the late Callovian over the Middle East platform and produced the same type of the formation that reflects the deposition under deep-water (euxinic) conditions. These reducing conditions were favorable for the accumulation of the organic materials within the Najmah formation, which is currently considered as the best source rock for oil generation so far in the whole Jurassic section.

The Najmah Formation varies in thickness from about 140 ft (42.7 m) in the north to 220 ft (67.0 m) in the south. The Najmah Formation comprised of Najmah Shale and Najmah Limestone, and is divided into 1) Upper Najmah, 2) Middle Najmah Shale, 3) Najmah Shale and 4) Lower Najmah Shale (Figure 4).

The oil accumulations in Najmah Sargelu reservoirs are formed because of unique geology characterized by organic rich mature source rock interlayered with tight fractured carbonate rocks. The productivity of this low matrix porosity reservoir (<5%) is enhanced by the occurrence of natural fractures created as a consequence of folding and faulting, some of which remained open through a combination oil recharge, and high reservoir pressures coupled with horizontal stress anisotropy.

**Najmah organic rich/Kerogen interval**

Organic rich Kerogen layer of Lower Kimmeridgian to Upper Oxfordian age, deposited throughout Kuwait, is a TOC rich layer with varying TOC content between 2 to 20 wt. percentage and having an average TOC of about 8wt. percentage. The depth of occurrence of this layer favorably places this zone to be having potential in rich gas condensate resource in the northern part of Kuwait. This layer occurs at a depth of 14000-16000 feet with a reservoir temperature of 270-275F, pressure of 11000 psi and average thickness of over 50 feet. This is one of the main source rocks for majority of the oil and gas fields of Kuwait. This Kerogen section is penetrated through a number of vertical wells, as part of development of deeper reservoirs in this area, which offers an excellent opportunity to evaluate this section through core and open-hole log data.

Vitrinite reflectance was utilized to estimate thermal maturity of the resources. Cooler colors (blues) represent early oil maturity and warmer colors (dark green to red) represent late peak oil to early wet gas maturity (Figure 6). Petrophysical analysis consistently identified the upper portion of the Lower Najmah Shale as the principal kerogen-rich zone exhibiting world class source rock potential (Figure 7). XRD data and geomechanical analysis results suggest the Lower Najmah Shale is most similar to and potentially analogous to the Eagle Ford Shale play in the US (Figure 8).

The Kerogen is inferred to be Type II, Oil & Gas prone based on Vitrinite reflectance values of 0.98 to 1.17. Gas shows were encountered during drilling through this interval in all the wells drilled for deeper targets. However, no extensive well tests have been undertaken in the Kerogen section, as the chance of success in vertical wells is limited due to Nano-Darcy permeability. A few permeability measurements have been carried out on cores from the Kerogen. The permeabilities measured are a factor of 100-1000 times lower than for similar porosities in the limestone facies

**Cretaceous Source Rock- Unconventional Play**

The Lower Cretaceous of Kuwait ranges in age from Berriasian to Aptian. It is an episode of passive rifting with a gradual return to open marine deposition from the more restrictive intra-shelf conditions that prevailed during late Jurassic times. Basal parts of the Lower Cretaceous section, locally known as the Makhul Formation was deposited in low energy, partly euxinic conditions. The formation consists of poor reservoir quality deposits.

**Makhul Formation**

The Makhul Formation is the lowermost mainly Cretaceous Formation; however, the basal part of the formation is considered Upper Jurassic. This basal part consists of argillaceous mudstone to packstone and is considered a source rock. The Formation had shown hydrocarbon potential in Minagish field and the basal unit is also considered a target for unconventional hydrocarbons. The Makhul Formation is overlain by the Minagish Formation, which was deposited in more open marine, moderate energy conditions in a deepening upward ramp setting.

The Makhul Formation constitutes Early Cretaceous carbonate with organic-rich shale. The thermal maturity model for the Makhul (Al Khamiss et al., 2009) indicated that Northwest Kuwait is more mature and therefore more prospective. Total organic carbon in the Makhul is 4% to 7%. Thermal maturity (vitrinite reflectance Ro 0.6 to 1.0) is early mature to late mature oil window. The hydrocarbon transformation ratio is 0.07 to 0.68, adequate in part for shale oil production. Makhul Formation is considered the most likely source of Cretaceous age hydrocarbons and a significant contributor to known accumulations.

Makhul Formations exhibit unconventional reservoir potential analogous to a hybrid unconventional reservoir system with tight non-shale reservoirs interbedded with organic-rich shales. Petrophysical modeling results (Figure 9), XRD data and overall lithologic character suggest that Makhul interval is potentially analogous to proven unconventional plays of Midland and Delaware basins in the US. Although the kerogen rich Lower Makhul Formation averages approximately 26 feet in a North Kuwait study area, the section averages approximately 150 feet, and up to 390 feet interval with greater than 1% TOC. The large thickness of greater than 1% TOC has the potential to generate large volumes of hydrocarbons thereby mitigating the source risk of the Makhul Formation.

## Challenges for Development of Unconventional resources in Kuwait

The exploitation of unconventional resource in Kuwait is very challenging. When compared to the other unconventional resources globally, the main Kerogen intervals in Kuwait appear relatively thin, and occur deeper in the subsurface with High Pressure/ High Temperatures with extremely high TOC. There is no available analogue regionally or globally that could provide a reference case for exploration and exploitation strategies and dealing with challenges associated with unconventional resource development. These challenges will require tailor made innovative technologies very specific to Kuwait to produce successfully at economic rates. The key challenges identified are shown in Figure 10.

## Drilling Challenges

Unlike unconventional resource plays around the globe, Kuwait has some unique challenges, which must be accounted for and overcoming with the proper use of innovation to successfully produce. One major challenge is the thickness and the depth of the kerogen rich interval of Najmah formation which is the main unconventional resource. Development of unconventional resources requires advanced technologies viz., horizontal drilling, pad drilling, and geosteering. Significantly overpressured and high temperature hazardous Gotnia Formation overlies the Najmah Formation. The upper Jurassic Hith and Gotnia Formations are a conformable succession of evaporite deposits. The Gotnia Formation consists primarily of thick sections of massive salt with secondary beds of anhydrite interbedded with limestone, dolomite, and shale.

The following challenges that are unique to Kuwait have to be overcome to achieve economic success:

- Uncertainty on well productivity and sustained rates: Currently there are no vertical or horizontal fracture-stimulated wells in either the Najmah or Makhul kerogen Formations to confirm producibility from these assets.

- New techniques and technology: Finding the appropriate fracture technology, such as multi-stage fractures, and mode of execution presents a significant challenge and will require a high level of expertise.
- Tectonic and structural complexity: Kuwait has a particular tectonic and geomechanical situation that could have a significant influence on completion and fracture design. Detailed geomechanical modelling and the associated data acquisition is therefore of primary importance.
- Natural fractures: The presence of natural fractures in some areas has influence on completion and fracture design and fracture connectivity with adjacent water zones.
- Limited thickness of kerogen units: This affects fracture stimulation containment.
- Cement isolation: Preventing water production from adjacent zones is crucial for economic development, and cement isolation is key to containing it.
- Sulfur content: High sulfur content is present in some areas and will complicate the drilling, completion, and production phases of any unconventional resource development.
- Water availability: Large amounts of water for fracture stimulation will be required.

**Surface challenges**

As the unconventional resource plays exist throughout Kuwait, identifying key “sweet spot” opportunities will help to drive the economic development of these assets. Once these opportunities are identified, large areas will be required for surface fracture stimulation that could be difficult in some areas of existing infrastructure congestion or agricultural land. There may be an advantage in this respect for development of unconventional resources off structure should they prove most economically advantageous.

**General challenges**

Unconventional reservoirs in Kuwait are diverse. While aspects of the Kuwait Class-1A organic rich/kerogen resources exist in analog resource plays around the world such as the Eagle Ford in South Texas, U.S.A., there are no true analogs yet that can reflect the geologic and engineering complexity that is expected to occur during unconventional resource development in Kuwait.

## Conclusion

To meet the ever-increasing demand for hydrocarbon resources and to maintain its competitive position in line with Year 2040 target, KOC has embarked upon an aggressive campaign to establish and develop unconventional reservoirs in this largely mature oil province. KOC constituted a Core committee for Unconventional Resources to co-ordinate efforts, consolidate resources and develop strategies for an effective development of these resources.

Various studies have been carried out over the past few years to characterize and evaluate the conventional resources in Kuwait. Significant unconventional resources potential is established in Lower Najmah Shales of Jurassic Age and Makhul Shales of Lower Cretaceous Age. The current approach and objective is to consolidate the potential of various unconventional resources of Kuwait and to classify them for an effective exploitation and development. These resources have been classified into three major types viz., Organic-rich formation (Class-I) which are the main source rocks for the oil and gas across the entire Kuwait, Tight formations (Class-II) and Mobile/immobile heavy oil reservoirs (Class-III).

However, the current focus is on the exploitation of kerogen rich zones of Class-I. In the initial phase, efforts are on to identify potential target locations exclusively for tapping Kerogen layers. More studies are being undertaken to evaluate and mitigate potential operational challenges envisaged while Drilling, Well placement and Hydraulic Fracturing.

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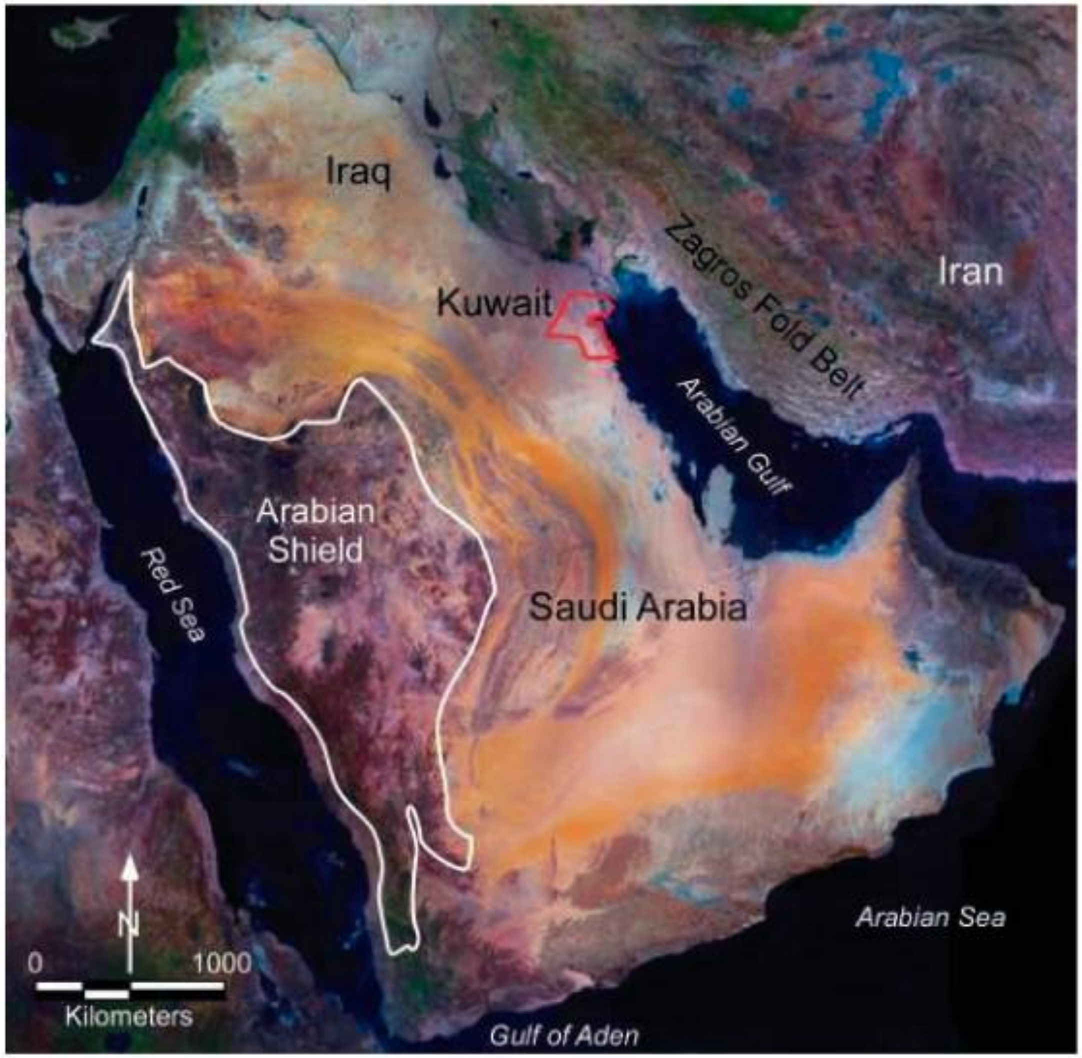



Figure 1. Landsat image of Arabian Peninsula.

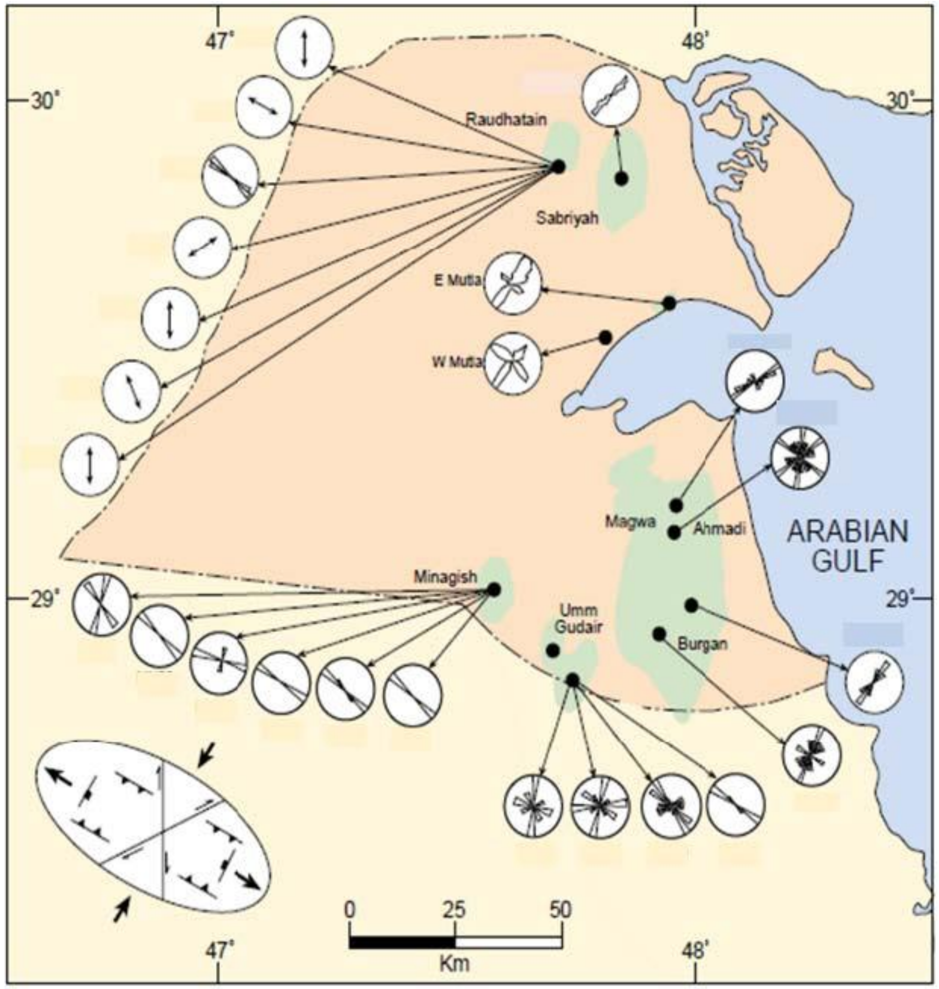



Figure 2. Regional Stress Field Indicators map.

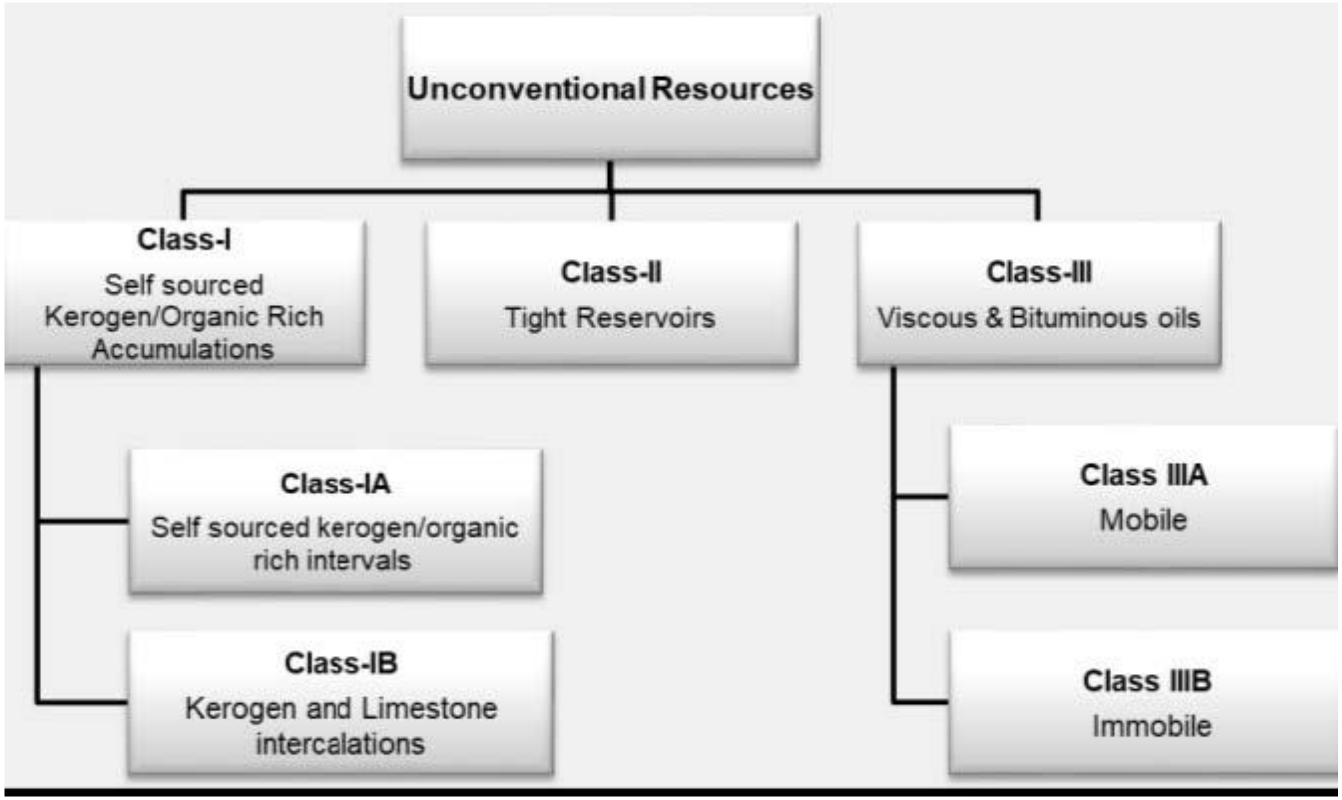



Figure 3. Classification of Unconventional Resources.

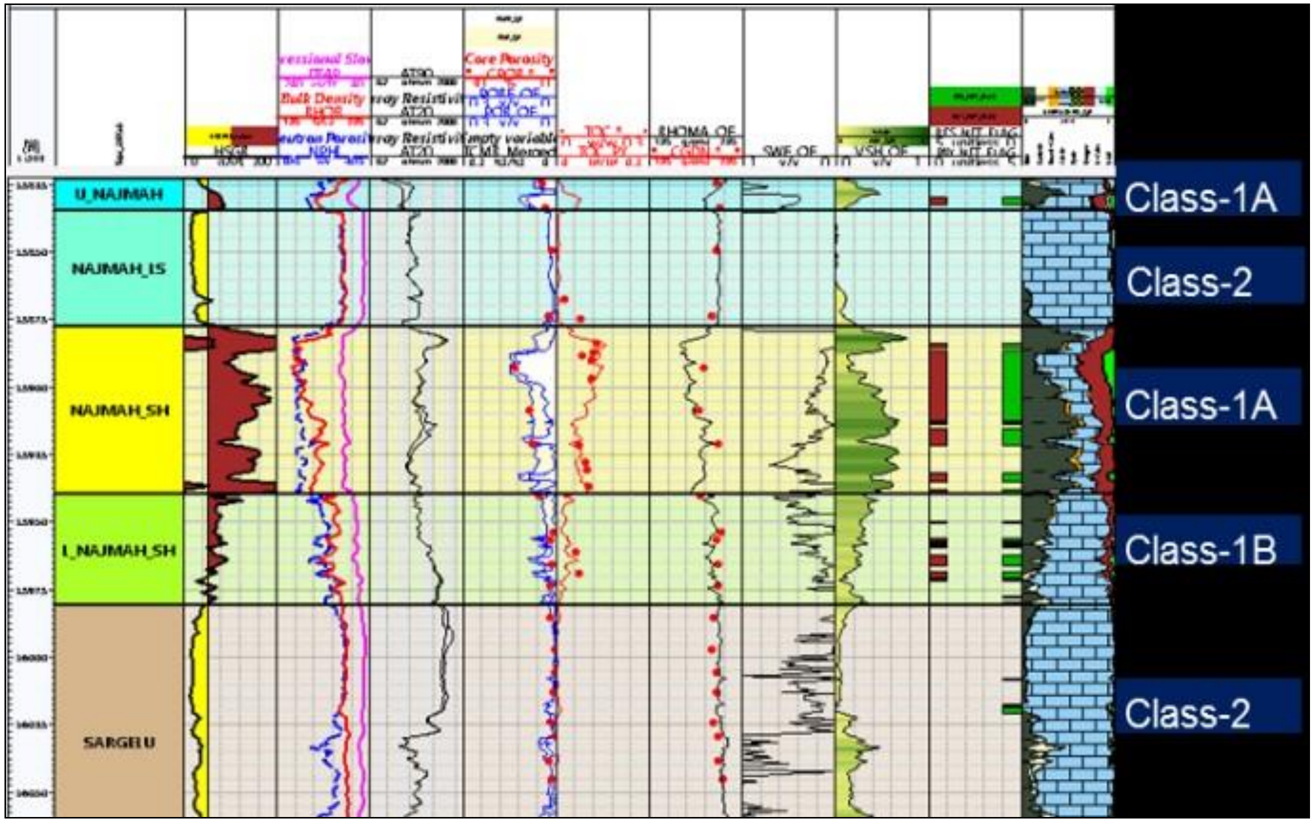



Figure 4. Typical log signatures defining Unconventional Resource Classes in NJ-SR section.

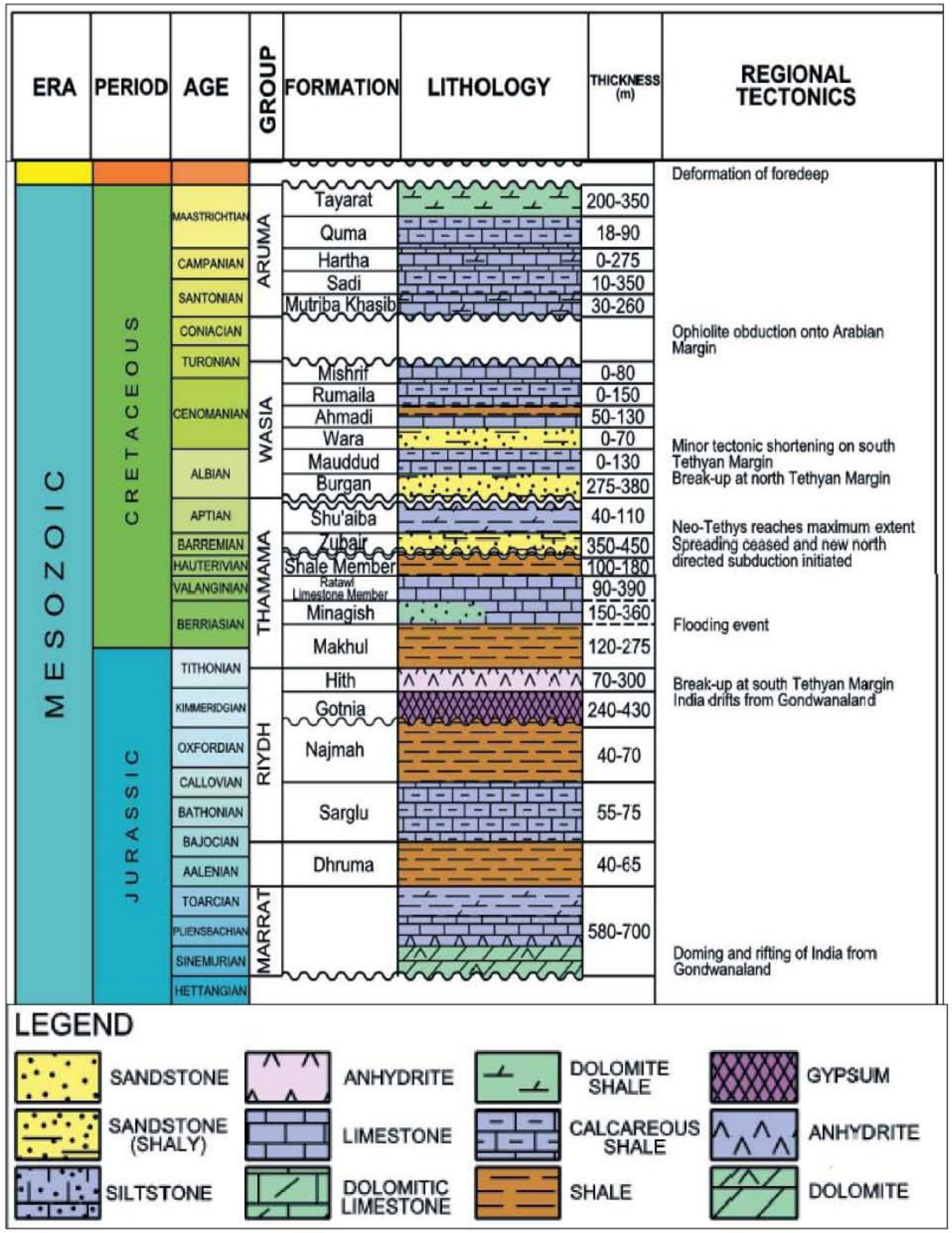



Figure 5. Jurassic-Cretaceous Stratigraphy of Kuwait.

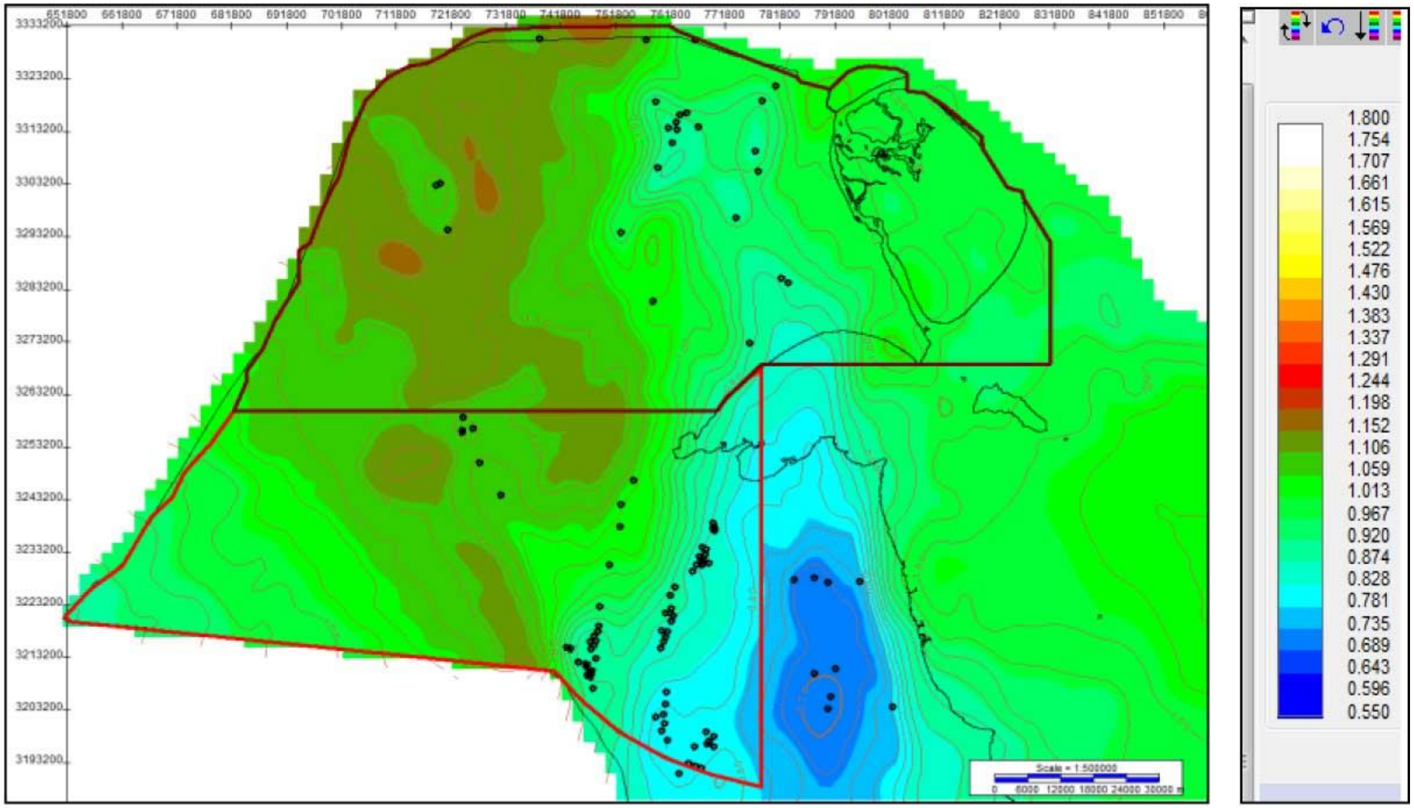



Figure 6. Vitrinite reflectance map showing Najmah Kerogen reservoir.

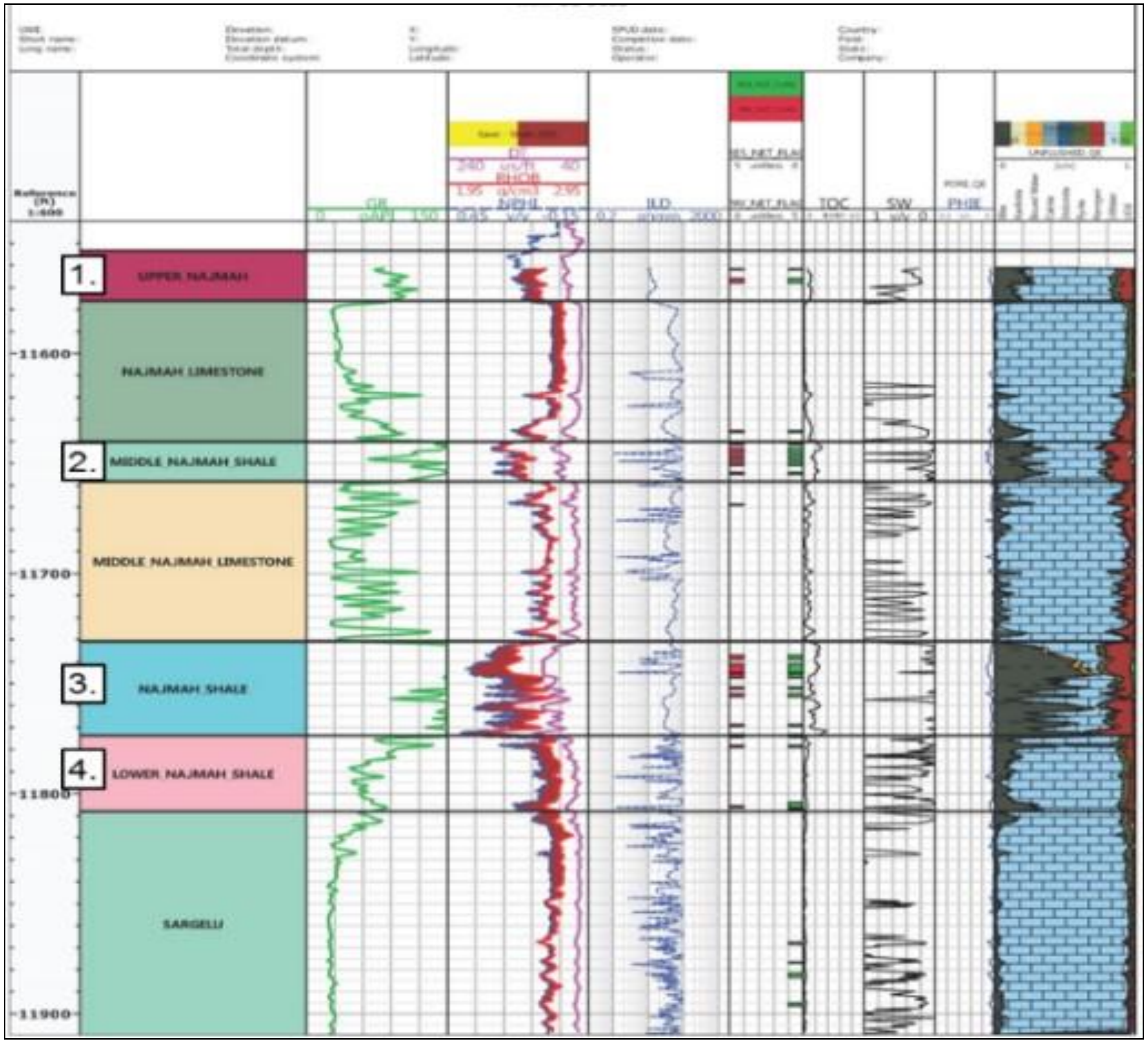
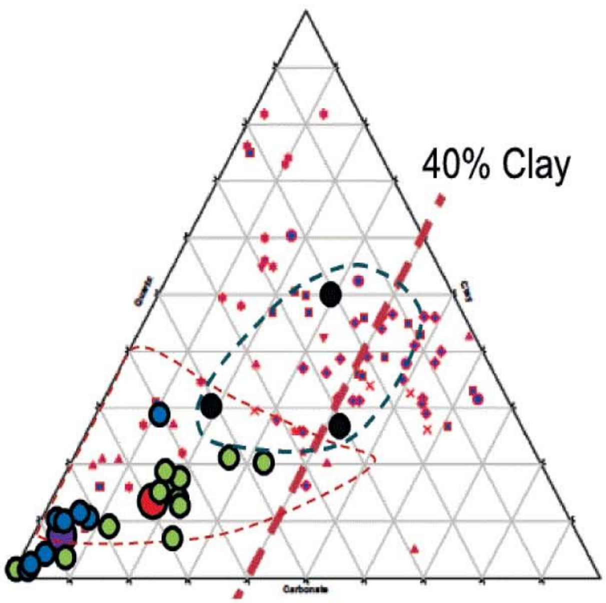



Figure 7. Typical well log showing Najmah formation.




| | Eagle Ford | Lower Najmah Shale |
|---|---|---|
| Net Pay (feet) | 50 to 300 | 60 to 120 |
| TOC (%) | > 4 | > 4 |
| Porosity (%) | 10 to 15 | 6 |
| Water Saturation (%) | 7 to 31 | 6 |
| Young's Modulus (psi) | 1 to 3,000,000 | > 3,000,000 |
| Poisson's Ratio | 0.25 to 0.27 | 0.22 to 0.33 |

*Fig.8. Quartz-Carbonate-Clay Ternary Plot showing Najmah and Makhul shales vis-à-vis Eagle Ford Shale plays of US*

*Background data is from eight US shale plays (Modified from SPE 125525, Britt, L and Shoeffler, 2009)*

Figure 8. Quartz-Carbonate-Clay Ternary Plot showing Najmah and Makhul shales vis-à-vis Eagle Ford Shale plays of US. Background data is from eight US shale plays (Modified from SPE 125525, Britt, L and Shoeffler, 2009).

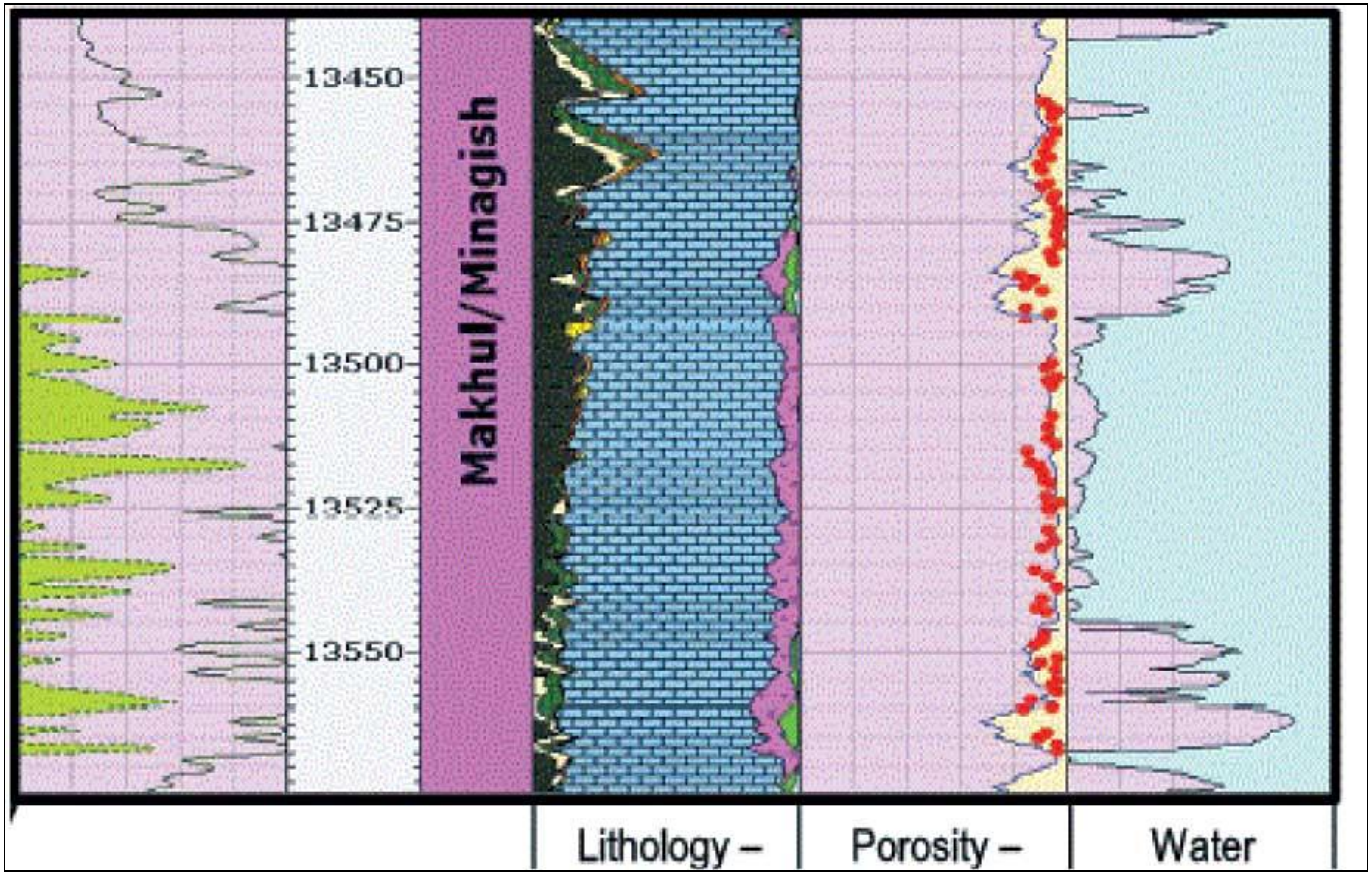



Figure 9. Lower Makhul section showing Kerogen interval.

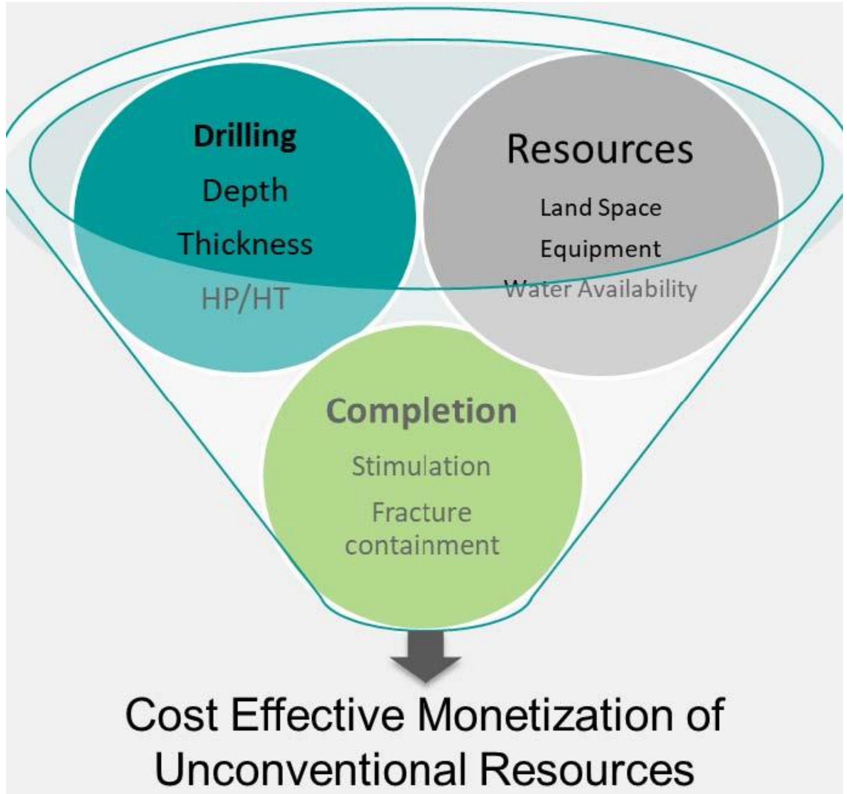



Figure 10. Identified Challenges for Unconventional Resource Development in Kuwait.

| STAGE 1 | STAGE 2 | STAGE 3 | STAGE 4 |
|---|---|---|---|
| INITIAL RESOURCE ASSESSMENT | EXPLORATION PILOT | APPRAISAL PILOT | DEVELOPMENT |
| • Identify resource opportunity<br>• Identify areas for exploration pilot | • Refine areas for appraisal<br>• Targeted data acquisition and study to reduce uncertainty<br>• Prove technology-experimentation<br>• Establish reservoir producibility | • Prove technology<br>• Prove commerciality - experimentation<br>• Further delineation | • Demonstrate potential commerciality across the play<br>• Optimize EUR and cost |
| 1-2 Years | ~2 Years | ~3 Years | |

Table 1. Schematic Chart for Exploration & Development of Class-1A.